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ECONOMIC PERFORMANCE OPTIMIZATION OF A HYBRID PV- BESS POWER GENERATOR: A CASE STUDY LA REUNION ISLAND

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Abstract. *This paper proposes an economic performance optimization strategy for a PV plant coupled with a battery energy storage system (BESS). The case study of La Reunion Island, a non-interconnected zone (NIZ) with a high level of renewable energy sources (RES), is considered. This last decade, to reach the ambitious target of electricity autonomy by 2030 set by the local authorities, local and national plans have been launched to promote RES integration that led to a noticeable development of photovoltaic (PV) systems. To avoid a decrease of the grid reliability due to a large integration of intermittent energy sources into a non-interconnected grid, the authorities have introduced new regulatory rules for RES producers. The proposed optimization strategy relies on these new regulatory rules and takes into account the energy market data, the amount of PV production subject to penalties for imbalance, the batteries and the PV technological characteristics together with a PV production forecast model. The effectiveness and relevance of the proposed strategy are assessed on experimental data collected on a real PV power plant. An economical analysis demonstrates that the proposed optimization strategy is able to fulfill the new regulatory rules requirements while increasing the economic performance of the system.*

1. Introduction

To date, reducing carbon emission has become a major concern. Among possible options, increasing shares of renewable energy sources (RES) such as solar, wind or biomass resources appears as a promising solution for a cleaner power generation. High shares of RES may then become a critical aspect of future energy systems. In this context, small islands that mainly rely on imported fossil fuels for energy production are likely to be pioneers in the development of decarbonized electricity production [1-2].

In this study, the case of La Reunion Island, a non-interconnected zone (NIZ), is considered. Even if the territory has a high level of RES, its electricity production remains strongly based on imported fuels. In this context, local authorities have set the ambitious objective of reaching electricity autonomy by 2030. This last decade, to reach this target, local and national plans have been launched to promote RES integration [3-4]. Thus, supported by incentive mechanisms such as tax exemptions, direct subsidies or feed-in tariffs, photovoltaic (PV) systems have experienced a rapid and noticeable development [5]. However, a large integration of intermittent sources into a non-interconnected grid raises critical technical issues due to the uncertainties of the energy production. The intermittency and unreliability of solar-generated power may reduce the network stability and lead to load shedding or to the interruption of electric service [6]. To avoid such situations, the authorities have set a limit of 30% of intermittent sources in the instantaneous electricity production and have introduced new regulatory rules for RES

development. Henceforth, RES producers have to declare to the grid operator, a day in advance, the power profile that will be injected to the grid. Then, if the power plants do not meet the submitted schedule for injected power, they face financial penalties. In La Reunion Island, if mismatches between actual and scheduled power injection exceed a given tolerance, RES producers are charged with imbalance penalties. In order to address the problem related to the intermittency of solar-generated electricity while reducing the amount of PV production subject to penalties for imbalance, energy storage systems (ESSs) appears as one of the most relevant option. Recently, several works related to the applicability, advantages and disadvantages of various ESS technologies for RES integration have been reported [7]. As regards PV power plants coupling with ESS, several works dealing with technical issues and economic feasibility have been conducted [8-11]. However, from a regulatory point of view (incentive schemes and economic feasibility), nearly all works reported in the literature focus on the determination of the optimal sizing of the ESS [12-15].

In the case of La Reunion, and according to our best knowledge, none work has been conducted to optimize the economical performance of existing hybrid photovoltaic-battery energy storage system (BESS) power generators, based on the latest regulatory rules. In this paper, an economical optimization of a hybrid PV-BESS power generator is developed. The proposed methodology relies on a *metaheuristic* optimization algorithm taking into account the energy market data, the amount of PV-generated energy subject to penalties for imbalance, the PV and the batteries

1 technological characteristics together with a PV production 33
 2 forecast model. To assess the effectiveness and relevance of 34
 3 the proposed strategy, the economic analyses are performed 35
 4 on data measured on a real power plant. Indeed, a one-year 36
 5 experimental data, collected from August 2013 to August 37
 6 2014 on a 57 kWp PV farm coupled with a 78.5kWh BESS, 38
 7 are considered. 39

8
 9 The rest of this paper is organized as follows. The regulatory 41
 10 rules applied in La Reunion are presented in Section 2. 42
 11 Section 3 is dedicated to model design. In this section the PV 43
 12 production forecast model and the energy storage model are 44
 13 detailed. The performance of the proposed optimization 45
 14 strategy in terms of economical efficiency improvement is 46
 15 demonstrated in Section 4. 47

16
 17 **Table 1:** Nomenclature. 49

Variable	Description [unity]	
P_{bid}	Scheduled profile to be injected to the grid [kW]	50
P_{inj}	Power injected to the grid [kW]	51
P_{PV_m}	Measured PV power [kW]	52
P_{PV_f}	Forecasted PV power [kW]	53
P_{PV_peak}	Installed PV power capacity [kW _p]	
P_{sto}	Storage power [kW] (>0 charge, <0 discharge)	
P_{sto_AC}	Storage power exchanged with the AC bus	
$-P_d$	Maximal power in discharge [kW]	54
P_c	Maximal power in charge [kW]	55
P_l	Imbalance power [kW]	56
E_{sto_peak}	Amount of energy dedicated to evening peak [kWh]	57
$E_{PV_f_total}$	Estimated total energy produced by PV plant [kWh]	58
α_{peak}	Parameter to be estimated	59
$\beta_{forecast}$	Parameter to be estimated	60
C_{max}	Maximum usable storage capacity [kWh]	61
SOC_{min}	Min. energy storage level [% C_{max}]	62
SOC_{max}	Max. energy storage level [% C_{max}]	63
η_c	Efficiency of storage in charge	64
η_d	Efficiency of storage in discharge	65
C_s	Electricity selling price	66
C_b	Electricity buying price	67
DFR	Daily fault rate	68
τ_{fault}	Cumulated time of faulty condition [minute]	69

70
 71
 72
 73 **2. Regulatory rules** 74

75 In NIZ such as La Reunion, the large integration of 76
 77 intermittent sources raises critical technical issues related to 77
 78 the reliability of power supply. The reliability of an electrical 78
 79 grid can be defined by its ability to supply the aggregate
 80 electrical demand and energy requirements of the customers
 81 at all times, while withstanding sudden disturbances such as
 82 unanticipated loss of system elements (e.g. load or production
 83 fluctuations) [16-18]. Currently the sustainability of power 79
 80 supply in La Reunion is already lower than in Metropolitan 80
 81 France, with an average power outage duration estimated at 81
 82 4 h/year/consumer vs 73 min [5]. In this context, and 82
 83 considering the rapid and important growth of PV systems in 83
 84 La Reunion the last decade, the authorities have recently 84

decided to set up new regulatory rules to ensure the reliability
 of the power supply. Henceforth, producers have to declare a
 one minute based profile that represents the day-ahead
 forecasted power to be injected by their plants. If the
 mismatches between the actual injected power and the
 announced power exceed the admitted tolerance, financial
 penalties are applied. According to this regulatory framework,
 energy imbalance is calculated with minutely resolution, and
 the tolerance band is taken equal to $\pm 5\%$ of the installed PV
 power capacity (P_{PV_peak}).

The electricity tariff system relies on peak and off-peak hours.
 During peak hours, 7PM to 9PM, the electricity feed-in tariff
 is more attractive. However, during this time period,
 producers have to guarantee a constant power injection to the
 grid comprise between 20 % and 70 % of P_{PV_peak} . The
 current electricity tariff system applied to PV power
 producers in La Reunion, including peak and off-peak feed-in
 tariffs, is summarized in **Table 2**.

Table 2: Summary of tariff system in La Reunion.

	Peak hours (7PM to 9PM)	Off-peak hours
	[€ ct/kWh]	[€ ct/kWh]
Selling price (C_s)	60	40
Buying price (C_b)	40	40

Note that producers have the possibility to buy electricity
 from the grid. In some very specific cases, it could be
 interesting to buy electricity from the grid during off-peak,
 store the energy in an ESS, and sell it back during peak hours.

The producer's revenue is calculated each minute using the
 following expression:

$$\text{revenue} = P_{inj} C_s/60 - P_{out} C_b/60 - \text{penalties} \quad (1)$$

where P_{inj} denotes the power injected to the grid and P_{out} the
 power extracted from the grid. The financial penalties are
 calculated as follows:

$$\text{if } P_{bid} - 0.05 P_{PV_peak} < P_{inj} < P_{bid} + 0.05 P_{PV_peak} \quad \text{then} \\ \text{penalties} = 0$$

$$\text{elseif } P_{inj} > P_{bid} + 0.05 P_{PV_peak} \quad \text{then} \\ \text{penalties} = P_{inj} C_s/60$$

else

$$\text{penalties} = \frac{C_s}{60} \left[P_{inj} \frac{P_{inj}}{P_{PV_peak}} - \left(0.1 + \frac{2P_{bid}}{P_{PV_peak}} \right) P_{inj} \right. \\ \left. + (P_{bid} - 0.05 P_{PV_peak}) \left(0.015 - \frac{P_{bid}}{P_{PV_peak}} \right) \right]$$

where P_{bid} denotes the day-ahead schedule power profile to be
 injected to the grid.

Every time P_{inj} is outside the tolerance band, the system is
 said to be in faulty condition and financial penalties are
 applied.

1 In this work, the economic effectiveness of the system is 58
 2 assessed using two criteria, which are the revenue and the 59
 3 daily fault rate (DFR). This last criterion defines the ratio of 60
 4 time where the system is in faulty condition each day: 61

$$6 \quad DFR = \tau_{fault}/1440 \quad 63$$

7
 8 With 1440 minutes per day, τ_{fault} represents the cumulated 65
 9 time of fault condition in minute. 66

10
 11 To fulfill the requirements of the new regulatory rule, PV 68
 12 power producers have to announce a day in advance the 69
 13 power profile to be injected to the grid, which requires a PV 70
 14 production forecast model. Besides, regardless of the 71
 15 accuracy of the PV production forecast model, financial 72
 16 penalties due to imbalance are unavoidable. Therefore, to 73
 17 reduce financial penalties and above all take advantage of 74
 18 peak hours feed-in tariff, the use of ESS appears to be a 75
 19 relevant option. 76

21 3. Model design 77

22 PV production forecast model 79

23 In the literature, a wide variety of parametric and non- 80
 24 parametric forecast models have been reported [19]. 81
 25 Parametric models require a wide set of information about the 82
 26 PV power plant technology and its installation configuration. 83
 27 Non-parametric models are generally based on weather 84
 28 forecast models [20]. These limitations make the reliability 85
 29 and the suitability for "on field" uses of parametric and non- 86
 30 parametric forecast models questionable. 87

31
 32 In this study, regarding practical purposes, the widely used 88
 33 persistence model is chosen to forecast the PV output power 89
 34 at a minute basis. This is a simple model based on the 90
 35 assumption that the PV production of today is the same as 91
 36 yesterday [21]:

$$38 \quad P_{PV_f}(t) = P_{PV_m}(t - 1440) \quad (2) \quad 40$$

41 where P_{PV_f} and P_{PV_m} denotes respectively the measured and
 42 forecast PV output power at time t .

43 Even if this method does not take into account the intra-day
 44 variability of solar irradiance, it represents with a good
 45 accuracy the periodicity and seasonality of weather conditions 92
 46 (day/night and summer/winter cycles) [13]. Besides, as a low- 93
 47 tech approach compared with irradiance forecast based 94
 48 strategies, it has the merit of avoiding additional costs, which 95
 49 cannot be underestimated for small cases applications. 96
 50 Obviously, the accuracy of the PV production forecast could 97
 51 be improved using more sophisticated models but at the price 98
 52 of increasing complexity and computational cost. 99

54 Energy storage model 100

55 Regarding optimization purposes and according to the 101
 56 considered time scale (minutes in this study), a simplified 102
 57 static model is proposed. This model relies on the static

characteristics of the battery (Cf. table 3) and neglects the
 transient dynamics of the process. In the sequel, powers are
 considered negative (respectively positive) during the
 discharge (respectively charge) phase. In this context, the
 battery state of charge (SOC) at time t is computed by:

$$64 \quad SOC(t) = SOC(t - \Delta t) + P_{sto}(t)\Delta t/C_{max} \quad (3)$$

Subjected to constraints on power and capacity:

$$68 \quad \begin{cases} P_d \leq P_{sto}(t) \leq P_c \\ SOC_{min} \leq SOC(t) \leq SOC_{max} \end{cases} \quad (4)$$

70 where $P_{sto}(t)$ is the storage power at time t . $P_d < 0$, $-P_d$
 71 represents the maximum battery discharging power, and
 72 $P_c > 0$ the maximum battery charging power. SOC_{min} and
 73 SOC_{max} are the minimum and maximum battery state of
 74 charge, respectively. C_{max} denotes the maximum usable
 75 storage capacity of the ESS. Note that the battery aging and
 76 self-discharge rate, which obviously affect C_{max} , has not been
 77 considered. Besides, powers are considered constant during
 78 the time interval $[t; t + \Delta t]$. In this work, Δt is equal to one
 79 minute.

The PV, battery, grid, and loads are all connected to an AC
 bus. Since the battery is operated on DC, an AC-to-DC
 (respectively DC-to-AC) converter is necessary when
 charging (respectively discharging) the battery. Therefore,
 considering the storage charge and discharge efficiencies (η_c
 and η_d respectively), the storage power exchanged with the
 AC bus $P_{sto,AC}(t)$ is expressed as follows:

$$89 \quad \begin{cases} P_{sto,AC}(t) = P_{sto}(t) \eta_d & \text{if } P_{sto}(t) < 0 \text{ (discharge)} \\ P_{sto,AC}(t) = P_{sto}(t)/\eta_c & \text{if } P_{sto}(t) \geq 0 \text{ (charge)} \end{cases} \quad (5)$$

Table 3: Storage system parameter values.

Variable	Description [unity]	Value
C_{max}	Maximum storage capacity [kWh]	78.5
SOC_{min}	Min. energy storage level [% C_{max}]	20
SOC_{max}	Max. energy storage level [% C_{max}]	99
η_c	Efficiency of storage in charge	0.9
η_d	Efficiency of storage in discharge	0.9
$-P_d$	Maximal power in discharge [kW]	36.1
P_c	Maximal power in charge [kW]	17.2
DOD_{max}	Maximal depth of discharge [%]	80

4. Economic performance optimization

In this work, a minute dispatch strategy for a 57 kWp PV
 farm with 78.5 kWh BESS is implemented and an economical
 optimization of the dispatch strategy is proposed. BESS has
 two main applications: first, compensate PV production
 forecast errors during off-peak and thus reduce financial
 penalty due to imbalance. Second, inject power to the grid
 during peak hours and thus take advantage of the attractive
 feed-in tariff. In this context, two parameters are introduced.
 The first one, denoted α_{peak} , is related to the amount of

energy dedicated to the evening peak hours (E_{sto_peak}), which have to be stored in the BESS meanwhile, and is written as a fraction of the estimated total energy produced by the PV plant ($E_{PV_f_total}$):

$$E_{sto_peak} = \alpha_{peak} E_{PV_f_total} \quad (6)$$

Here $E_{PV_f_total} = \int_0^{1440} P_{PV_f} dt$. The second one, denoted $\beta_{forecast}$, represents the fraction of the storage capacity that is dedicated to compensate power imbalance ($C_{forecast}$) due to forecast errors:

$$C_{forecast} = \beta_{forecast} C_{max} \quad (7)$$

To assess the effectiveness and relevance of the proposed strategy, the economic analyses are performed on a one-year experimental data, collected from August 2013 to August 2014 at La Reunion on a real PV power plant. Due to its high convergence rate to the true global minimum and its perfect suitability to practical engineering optimization problems, the recently developed Modified Cuckoo Search algorithm proposed by [22] is used as optimization algorithm.

PV/BESS control rules

The power injected to the grid is defined as the sum of the PV output power and the storage power exchanged with the AC bus:

$$P_{inj} = P_{PV_m} + P_{sto_AC} \quad (8)$$

The BESS is used to adjust the PV power plant P_{PV_m} to maintain, as much as possible, the difference between the day-ahead announcement P_{bid} and the actual power injected P_{inj} to the grid within the tolerance band. If P_{PV_m} is above (respectively below) the tolerance limit, the BESS can be used, when it is possible, to store (respectively deliver) the imbalance power P_I . Depending on whether the measured output PV is within, below or above the tolerance band, P_I is defined as follows:

$$\begin{cases} P_I = 0 & \text{within} \\ P_I = P_{PV_m} - (P_{bid} + 0.05 P_{PV_peak}) & \text{above (charge)} \\ P_I = P_{PV_m} - (P_{bid} - 0.05 P_{PV_peak}) & \text{below (discharge)} \end{cases} \quad (9)$$

Every time $P_I \neq 0$ financial penalties for imbalance are applied. Therefore, the storage charge/discharge process must be suitably controlled in order to reduce the DFR and thereby the amount of financial penalties, while ensuring that there is enough energy stored in the BESS for the evening peak. In this aim, a tolerance band control strategy is proposed and a specific control rules is designed for each zone: above, within and below the band.

Above the upper limit

When P_{PV_m} is above the tolerance band, the BESS is used to compensate the imbalance power and store the excess of

energy whenever possible. Indeed, the imbalance power cannot always be compensated. Several conditions related to operational and technical limits of the BESS have to be verified (i.e state of charge, charge/discharge rate limits). In this case, the storage power is computed as follows:

$$P_{sto_AC} = \min(P_C/\eta_c, P_I, P_{sto_MAX}/\eta_c) \quad (10)$$

where $P_{sto_MAX} = (SOC_{max} - SOC(t))C_{max}/\Delta t$

Below the lower limit

When P_{PV_m} is below the tolerance band, the imbalance power due to forecast error can be compensated using the energy stored in the BESS. However, this energy has to be manipulated very wisely in order to ensure that enough energy remains to guarantee peak hours. The storage power is calculated according to operational and technical limits of the BESS and subjected to constraints on E_{sto_peak} and $C_{forecast}$:

$$P_{sto_AC} = \max(P_d\eta_d, P_I, -P_{sto_MAX}\eta_d) \text{ if } SOC(t) > E_{sto_peak}/C_{max} \\ \text{otherwise } P_{sto_AC} = 0 \quad (11)$$

where

$$P_{sto_MAX} = \min((SOC(t) - E_{sto_peak}/C_{max})C_{max}/\Delta t, C_{forecast}/\Delta t)$$

Within the tolerance band

When P_{PV_m} is within the tolerance band, the power imbalance is equal to zero and there is not need to absorb/inject power from/to the grid through the BESS:

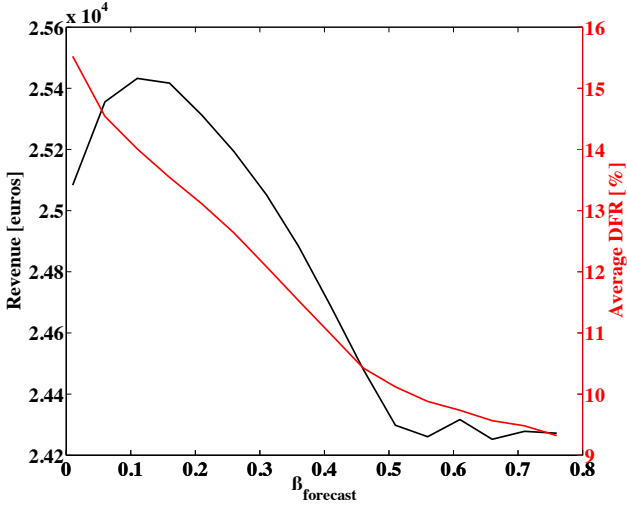
$$P_{sto_AC} = 0 \quad (12)$$

Economic performance improvement

The economical performance improvement relies on the estimation of two parameters α_{peak} and $\beta_{forecast}$. The effects of these parameters on the annual revenue and the average annual DRF are illustrated on **Fig. 1 and 2**.

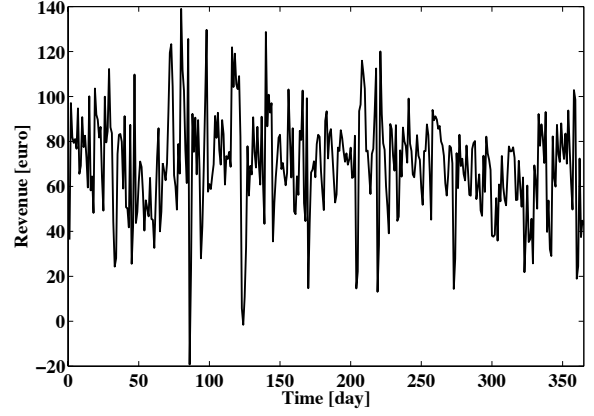
As expected, while $\beta_{forecast}$ is increasing the DRF is decreasing. Indeed, $\beta_{forecast}$ is straightforwardly linked to the fraction of the storage capacity dedicated to compensate power imbalance due to forecast errors. However, it is important to highlight that decreasing the DRF and so the financial penalties do not necessary means increasing the revenue. In fact, while $C_{forecast}$ becomes closer to C_{max} , the amount of energy that can be stored in the BESS for the evening peak hours decreases. Since peak hours feed-in tariff is more attractive than off-peak one, it could be more interesting to sell more energy during peak hours even if that means paying more penalties during off-peak due to forecast error.

As illustrated on **Fig. 2**, while α_{peak} is increasing the DRF is increasing, whereas the revenue increasing to a maximum before decreasing. Which seems indicate that, for a fixed value of $\beta_{forecast}$, there is an optimal amount of energy to store in the BESS for the evening peak hours.



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Fig. 1: Effects of $\beta_{forecast}$ on the revenue and the DRF (with $\alpha_{peak} = 0.3$ and calculated over one year)



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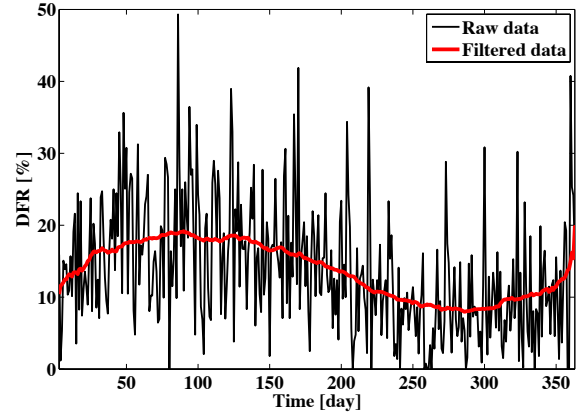


Fig. 3: Daily revenue and DRF obtain over one year

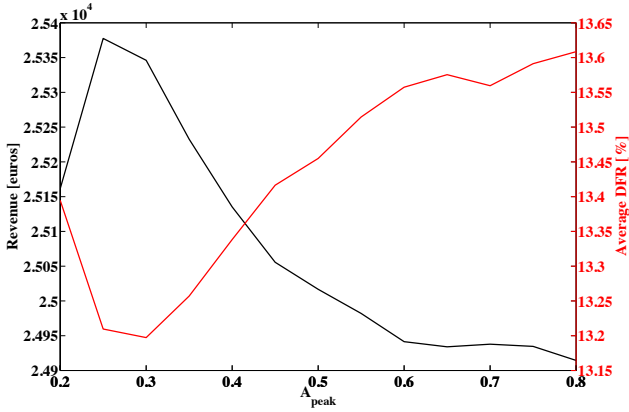


Fig. 2: Effects of α_{peak} on the revenue and the DRF (with $\beta_{forecast} = 0.2$ and calculated over one year)

Annual optimization

In a first attempt, the economic performance improvement strategy consists on finding the optimal values of α_{peak} and $\beta_{forecast}$ that maximizes the annual revenue. The optimization goal is to find the optimal set of parameter $\hat{p} = [\alpha_{peak} \beta_{forecast}]^T$ that maximizes the cost function J :

$$\hat{p} = \underset{p}{\operatorname{argmax}}(J) \quad (13)$$

with $J = \sum_{j=1}^{365} \sum_{i=1}^{1440} (P_{in}^{i,j} C_s / 60 - P_{out}^{i,j} C_b / 60 - Penalties^{i,j})$ and subjected to $p \in [p_{min}, p_{max}]$; $p_{min} = [0 \ 0]^T$; $p_{max} = [1 \ 0.8]^T$.

The optimization procedure, performed on experimental data collected from August 31st 2013 to September 1st 2014, leads to the optimal set of parameter $\hat{p} = [0.2978 \ 0.1387]^T$, which results to an annual revenue of 25 449.20 euros and an average DRF of 13.12%. The revenue and the DRF for each day are presented in Fig. 3.

It can be noticed that the DRF seems to contain a periodic component. The analysis of the DRF in the frequency domain reveals that the frequency component with the higher magnitude is located at $0.002732 \text{ day}^{-1}$, which corresponds to a periodicity of 366 days. Moreover, a thorough study of the DRF reveals a strong and significant correlation between DRF and the forecast error, with a Pearson's correlation coefficient of 82% ($p\text{-value} < 0.0001$).

The analysis of the forecast error reveals the same periodicity of 366 days, which means that the forecast error is linked to the season. Indeed, as illustrated on Fig. 4, the forecast error is higher in summer than in winter.

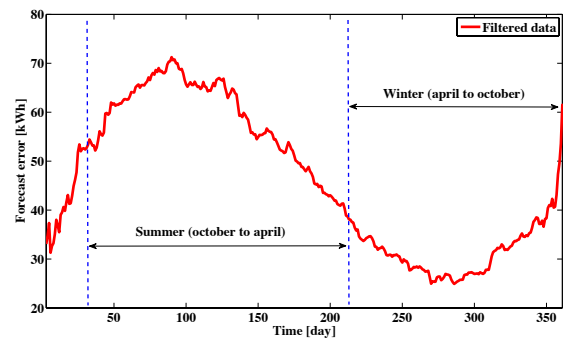


Fig. 4: Forecast error

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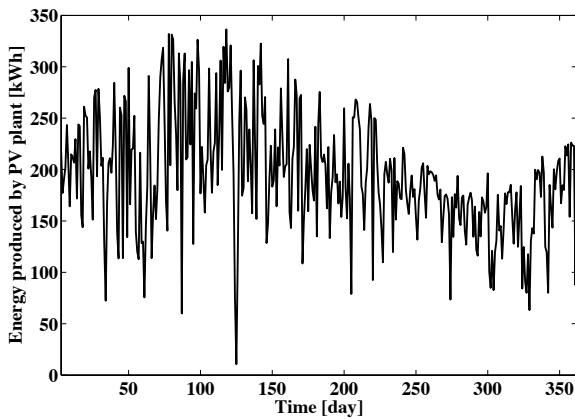
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1 This can be mainly explained by the fact that the forecast 43
 2 model does not take into account the intra-day variability of 44
 3 solar irradiance and that in La Reunion Island the intra-day 45
 4 variability is higher in summer. In this context, when the 46
 5 intra-day variability increases the error modeling increases 47
 6 too, which leads to an increase of the DFR. In other words, 48
 7 the seasonality of the solar irradiance variability introduces a 49
 8 seasonal component into the forecast error that is transmitted 50
 9 to the DFR.

10
 11 The analysis of the total energy produced by the PV plant 53
 12 each day ($E_{PV_f_total}$) reveals a seasonal component that is 54
 13 due to the yearly solar irradiance variability (Cf. Fig. 5). The 55
 14 amount of energy dedicated to the peak hours (E_{sto_peak}), 56
 15 which could have a strong influence on the revenue, is taken 57
 16 as a fraction of $E_{PV_f_total}$ using α_{peak} . In this context, the 58
 17 seasonal component contained into $E_{PV_f_total}$ is transmitted 59
 18 to E_{sto_peak} . A thorough study of intra-day and yearly 60
 19 irradiance variability in La Reunion can be consulted in [23]. 61
 20



21
 22 **Fig. 5:** Energy produced by the PV plant

23 Regarding the seasonality of the solar irradiance, and since 47
 24 $\beta_{forecast}$ and α_{peak} respectively influence the DRF and the 48
 25 amount of energy dedicated to the peak hours, it is likely that 49
 26 a seasonal-based or even a daily-based optimization of these 50
 27 parameters could increase the revenue. 51
 28
 29

30 6. Conclusions and prospects

31 In this work, a minute dispatch strategy for a 57 kWp PV 85
 32 farm with 78.5 kWh BESS has been simulated, and an 86
 33 economical optimization of the dispatch strategy has been 87
 34 developed. This strategy has been designed to fulfill the 88
 35 requirements of the new regulatory rules set in La Reunion 89
 36 while optimizing the economic performance of the system. 90
 37 The BESS is used during off-peak to compensate PV 91
 38 production forecast error and during peak hours to inject 92
 39 power to the grid. Therefore, two parameters have been 93
 40 introduced. The first one is related to amount of energy to 94
 41 store for the evening peak hours whereas the second one 95
 42 represents the fraction of the storage capacity that is dedicated 96

to compensate power imbalance due to forecast errors. The
 optimization goal is to find the optimal value of these
 parameters that maximizing the revenue while taking into
 account the new regulatory rules constraints. The proposed
 optimization strategy takes into account the energy market
 data, the amount of PV production subject to penalties for
 imbalance, the batteries and the PV technological
 characteristics together with a PV production forecast model.
 The effectiveness and relevance of the proposed strategy have
 been assessed on experimental data collected on a real PV
 power plant. An economical analysis demonstrated that the
 proposed optimization strategy has been able to fulfill the
 new regulatory rules requirements while increasing the
 economic performance of the system.

Due to the seasonal behavior of solar radiation, it is likely that
 economical performance can be further increased using a
 seasonal-based optimization approach. Additional works are
 currently in progress to study if the revenue can be increased
 by taking into account the seasonal component contained in
 the forecast error and the total energy produced by the PV
 plant.

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 72

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